Standard safety practices for Industrial Robots

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Report on standard safety practices for Industrial Robots

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Submitted to Dr. Sandipan Bandyopadhyay(IIT Madras) as a self study report

This document tries to summarize the practices undertaken for human safety when dealt with Industrial robots. Please note that this report is not exhaustive, but the content was accumulated from vast set of resources listed in References.

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1 Overview

An industrial robot is an automatically controlled, programmable, multi-purpose, manipulative machine with several degrees of freedom, for use in industrial automation applications. It may be either fixed in place or mobile.

They can perform unsafe, hazardous, highly repetitive and unpleasant tasks for humans. Furthermore, industrial robots, unlike humans, can perform complex or mundane tasks without tiring, and they can work in hazardous conditions that would pose risks to humans. Nowadays, industrial robots have been widely introduced to production lines and are expected to find more applications in the future. This is primarily due to the many merits of industrial robots that conventional machines do not possess. For example, robots are increasingly being used in industry to perform such tasks as material handling and welding, and there are around one million robots in use worldwide.

Safety is a key factor in industrial and service robot applications, making robotics safety an important subject for engineers. For instance, around **12-17%** of accidents in industries using advanced manufacturing technologies have been reported to be related to automated production equipment, including robots.

Safety standards become of utter importance when **human interaction** with the robot is very high, for example in case of training robots like Flight and Automobile simulators. Even in case of typical industrial robots, an employee is always appointed to the industrial workplace, the corrective maintenance worker. This individual is normally present during all operations of a robotics system and is responsible for assuring continuing operation - adjusting speeds, correcting grips, and freeing jam-ups. The corrective maintenance worker may also be the trained programmer who guides a robot through the teach-and-repeat technique. It is necessary for this individual to be near the robot from time to time, which raises concerns about his or her safety and the safety of other workers who may also be exposed.

Industrial robots are programmable units designed to form expected movements but, unfortunately, the movements of people who work with robots **cannot be predicted**, making robot safety very important. Recent studies in Sweden and Japan, as reported by ANSI-RAI, indicate that many robot accidents do not occur under normal operating conditions but rather during programming, adjustment, testing, cleaning, inspection, and repair periods. During many of these operations, the operator, programmer or corrective maintenance worker may temporarily be within the robot work envelope while power is available to moveable elements of the robot system.

Robot safety may be interpreted in various ways, including preventing the robot from damaging its environment, particularly the **human element** of that environment, and simply preventing damage to the robot itself. Without proper precautions, a robot experiencing a fault or failure can cause serious injuries to people and damage equipment in or around a work cell.

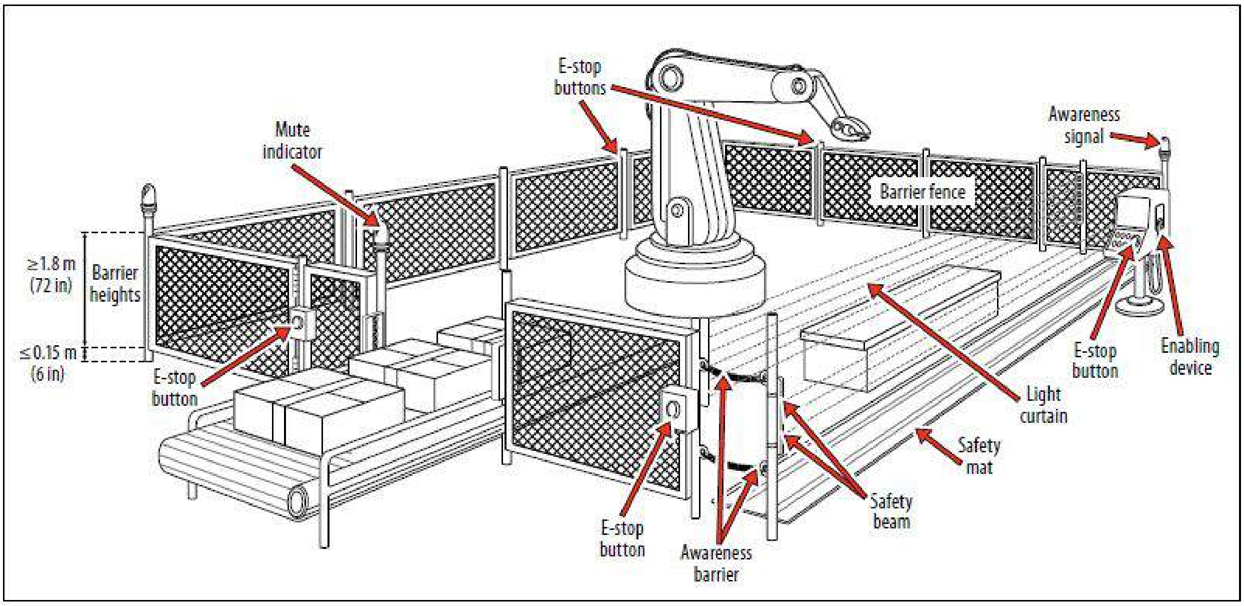


Figure 1: An effective safety system for industrial robot

Source: Environment, Health and Safety Department guidelines (`www.ehsdb.com`)

2 Sources of Hazards

The potential hazards posed by machines to humans can be assessed and broken down by source/cause, as follows: human interaction, control error, unauthorized access, mechanical failure, environmental source, power system fault and improper installation.

These are summarized in the flowchart show below:

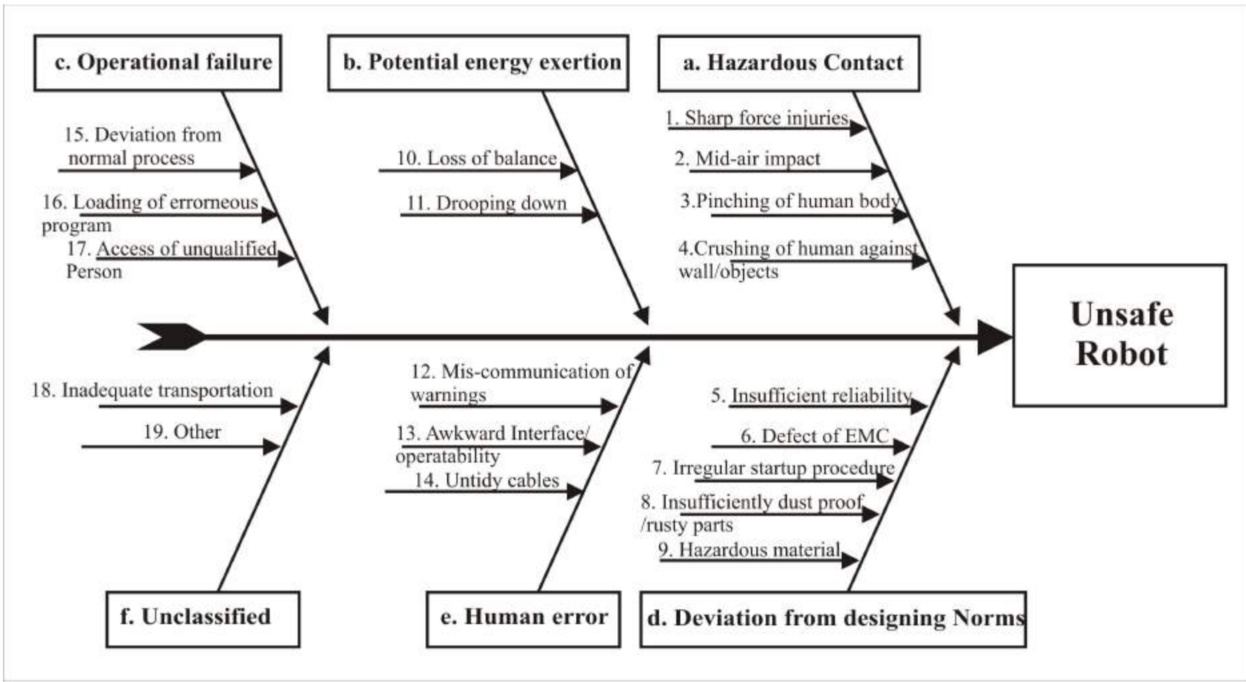
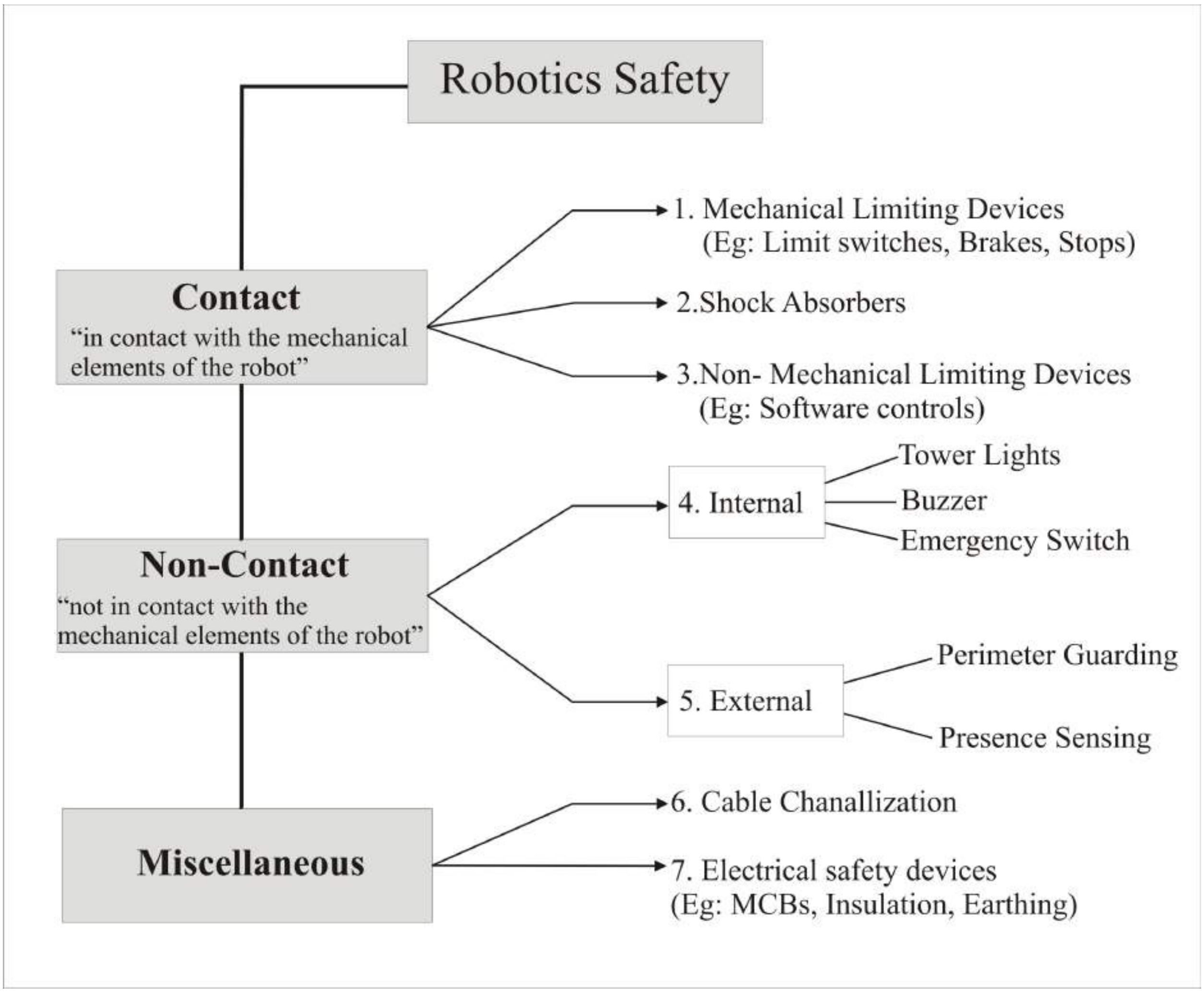


Figure 2: Sources of Hazards

3 Robot safeguards

Following flowchart classifies the safety measures for a robot based on the location from/on the robot.



All the safety devices are discussed one by one in the following sections.

3.1 Mechanical Limiting Devices

3.1.1 Limit switches

A switch operated by the motion of a machine part or presence of an object. It is an electromechanical device that consists of an actuator mechanically linked to a set of contacts. When an object comes into contact with the actuator, the device operates the contacts to make or break an electrical connection.

When robot reaches an extremity of its actuator space or say very near to a singularity position, these switches can be mechanically placed to get tripped and avoid any unwanted implications

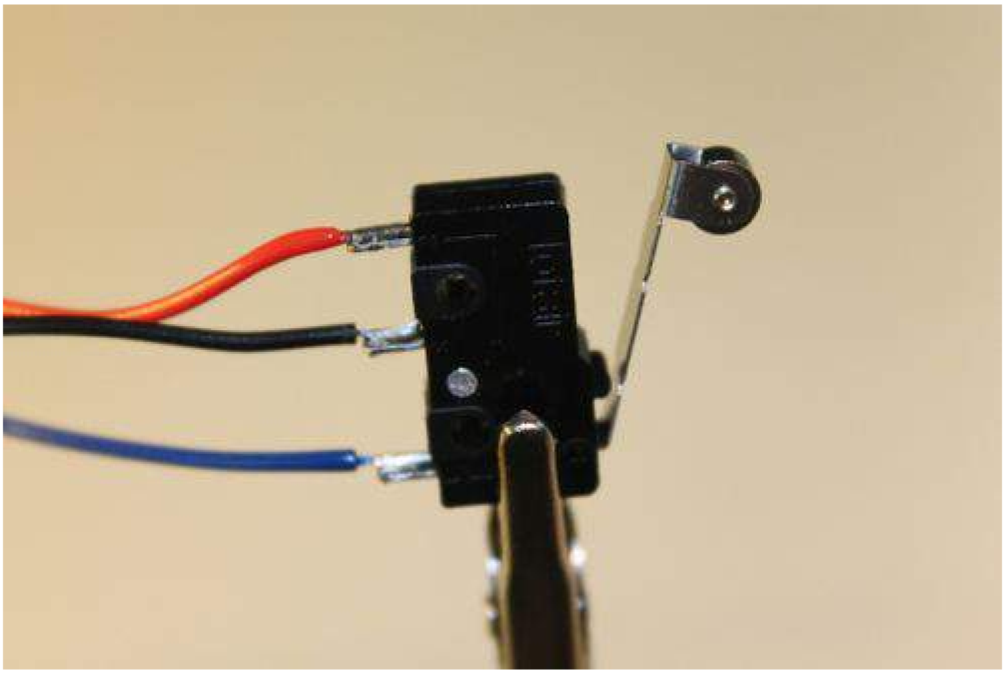


Figure 3: Limit switch

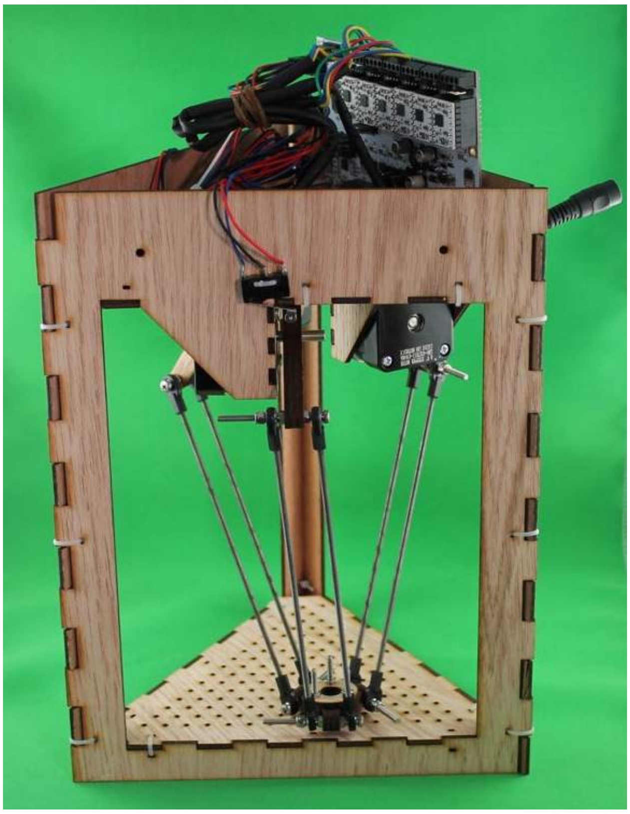


Figure 4: Limit switch mounted on a delta robot

Source: `learn.marginallyclever.com/index.php/Delta_Robot_3`

3.1.2 Brakes

Brakes can be used to support the weight of the arm and object in the event of a power failure. Mechanical brakes arrest the energy of a machine or object via force, most commonly friction. It locks down the manipulator ensuring no motion until the operator comes back to safe zone. Also helps in paralyzing the robot when there is chance of inter link collisions.

Figure 5: Mechanical Brakes

Source: www.cjmco.com

3.1.3 Mechanical stops

These limit the movement of a robot to maybe exclude the area not required to be operated or to safeguard some vital elements of the robot itself, eg Motors, Links etc.

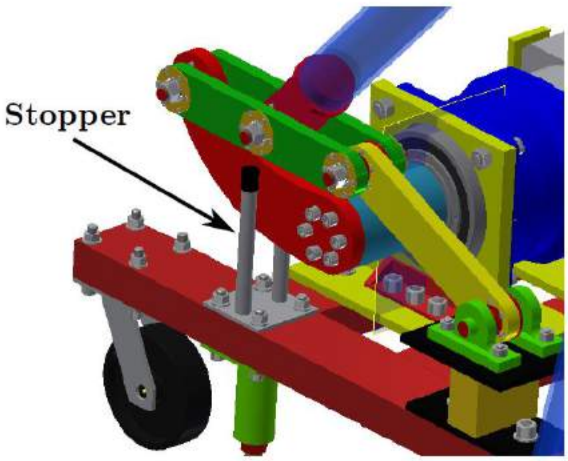


Figure 6: Mechanical stops

3.2 Shock absorbers

Some manually operated manipulators require user riding or sitting on it, eg: Flight or Automobile simulators, motion platforms. Special precautions are required when operator is at some height above the ground which usually is the case in motion platforms (Eg: Stewart platform).

If the actuator used is not pneumatic or hydraulic, emergency power failure calls for a strong mechanical brake or an elegant shock absorber to safe-land the operator.

Figure 7: Shock Absorber for safe landing of the operator

3.3 Non-Mechanical Limiting Devices

Often it is possible to limit the actuator space values using software or controller. In this case encoder no more allows the motor to attain the specific angular values. These are used with if-else structure responding to the inputs of sensors detecting human presence in robot working space.

3.4 Internal non-contact safety devices

These are the devices very near or on the robots which warn the operator of different scenarios through light signals or buzzers.

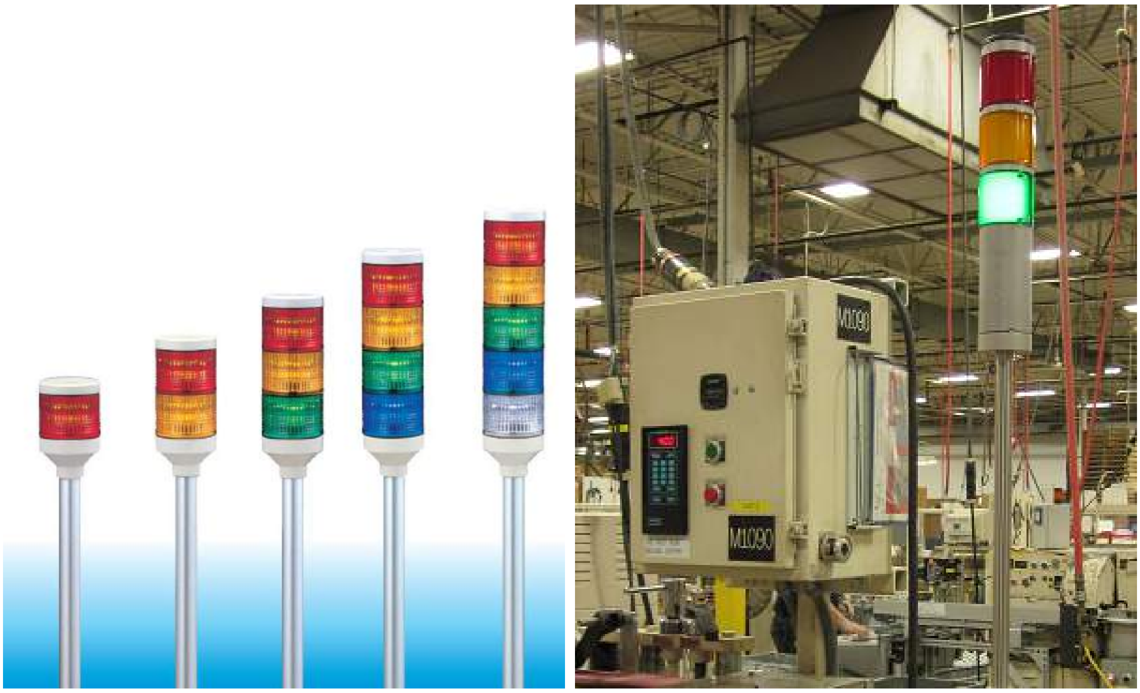
3.4.1 Tower lights

Also called Signal Tower or Stack lights, are commonly used on equipment in industrial manufacturing and process control environments to provide visual and audible indicators of a machine state or process event to machine operators and technicians.

Stack lights are generally columnar structures in a variety of shapes, placing color-coded indicator segments on top of one another in a "stacked" orientation. A stack light will typically have up to 5 differently coloured segments to indicate various conditions on the machine or process.

Flashing control may be provided by the stack light's internal circuitry or externally controlled with timers or logic controllers. Stack lights are available for all types of industrial environments including wash-down (IP65) and explosion proof.

Commonly used color codes for machine state conditions are summarized in table on next page.



(a) Tower lights (b) Tower lights in an industry

Figure 8: Source: Wikipedia- Tower Lights

Sr. No.	Color	Device type	Typical Function	Examples
1	RED	Push button	Emergency Stop, Stop, Off	Emergency Stop button, Master Stop button, Stop of one or more motors.
		Indicator light	Danger or alarm, abnormal condition requiring immediate attention.	Indication that a protective device has stopped the machine, e.g. overload.
		Illuminated Push button		Machine stalled because of overload
2	YELLOW	Push button	Return, Emergency Return, Intervention - suppress abnormal conditions.	Return of machine elements to safe position, override other functions previously selected. Avoid unwanted changes.
		Indicator light	Attention, caution/marginal condition. Change or impending change of conditions.	Automatic cycle or motors running; some value is approaching its permissible limit. Robot in action.
		Illuminated Push button	Attention or caution/Start of an operation intended to avoid dangerous conditions.	pressing button to override other functions previously selected
3	GREEN	Push button	Start-On	General or machine start; start of cycle or partial sequence
		Indicator light	Machine Ready; Safety	Indication of safe condition or authorization to proceed. Machine ready for operation with all conditions normal or cycle complete and machine ready to be restarted.
		Illuminated Push button	Machine or Unit ready for operation/Start or On	Start or On after authorization by lights; start of one or more motors for auxiliary functions; start or energization of machine elements.
4	WHITE	Push button	Any function not covered by thee above.	Control or auxiliary function not directly related to the working cycles.
		Indicator light	Normal Condition Confirmation	Normal pressure, temperature and other working conditions
		Illuminated Push button	Confirmation that a circuit has been energized or function or movement of the machine has been started/Start On	
5	BLUE OR GREY	Push button	Any function not covered by the above colors	
		Indicator light	Any function not covered by the above colors	
		Illuminated Push button	Any function not covered by the above colors	

3.4.2 Buzzers

A buzzer or beeper is an audio signaling device which may be mechanical, electromechanical, or piezoelectric. Typical uses of buzzers and beepers include alarm devices, timers and confirmation of user input.

Now a days tower lights comes with an in built buzzer and hence, one module of tower lights take care of both audio and visual indications.

Figure 9: Industrial Buzzer

Source: Wikipedia- Buzzer

3.4.3 Emergency push buttons

a safety mechanism used to shut off a device in an emergency situation in which it cannot be shut down in the usual manner. switch is designed and configured to completely and as quickly as possible abort the operation (even if this damages equipment) and be operable in a manner that is quick, simple (so that even a panicking operator with impaired executive function can activate it). Pushbuttons are also used for other purposes than emergency abortion. Summary of which is given in table 1.

(a) ES

(b) ES

Figure 10: Emergency Switch

Source: Wikipedia- Emergency Switch

3.5 External Non-Contact safety systems

3.5.1 Perimeter guarding

Fences are used to prevent entry to a robot working space as shown in Fig. 11 The fence also provides a preventive barrier against losing parts from the gripper. Barriers are a different type of protection preventing the worker from entering the cell through the load/unload area.

Figure 11: Perimeter fencing for an industrial robot

Source: `www.wirecrafters.com`

Barriers pose several potential advantages, such as

1. Their very existence (painted appropriately) is a warning even to someone unfamiliar to what they enclose and to casual observer.
2. Safety barrier preclude material-handling equipment and other vehicles in the plant from being inadvertently moved into danger zone.
3. Properly interlocked barrier gates tend to enforce procedural discipline when authorized personal tend to gain access to the work area.
4. Tempering with the equipment when it is not operating is minimized.

Clause 11.1 f) of RIA 15.06 calls out a maximum height off the floor of 0.3 m (12 inches) above adjacent walking surfaces. The minimum height to the top of the barrier can be no lower than 1.5 m (60 inches).

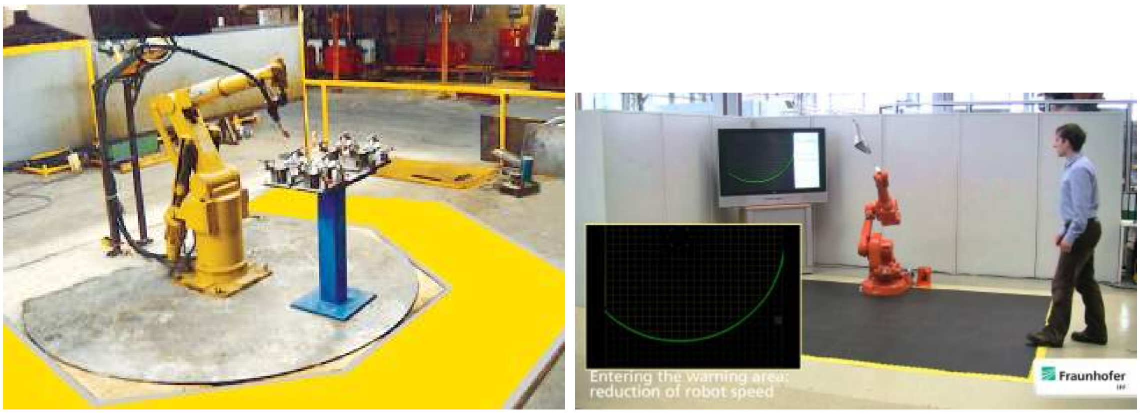
3.5.2 Presence Sensing and interlock devices

These are used to sense and react to potentially dangerous workspace conditions. Systems of this type include:

1. Pressure sensitive floor mat
2. Light Curtains
3. Laser scanning devices
4. End effector sensors
5. Computer vision

They are also designed to be fail-safe so that the occurrence of a failure within the device will leave it unaffected or convert it to a mode in which its failed state would not result in an accident. In some cases this means deactivation of the robot. Factors that are considered in the selection of such devices include the spatial limitations of the field, the environmental conditions affecting the reliability of the field and the sensing field interference due to robot operation. Details on different types of presence sensing devices follow:

Presence sensitive floor mat Pressure sensitive floor mats: These trigger an output if pressure is applied to the surface. Length of stride, speed of approach and system response time must be considered in placement.



(a) (b)

Figure 12: Pressure mat around a robot

Source: `www.londonmat.com` and `Fraunhofer.de`

ISO Standards: ISO 13856 is applicable to pressure-sensitive mats and pressure-sensitive floors, regardless of the type of energy used (e.g. electrical, hydraulic, pneumatic or mechanical), designed to detect

1. Persons weighing more than 35 kg, and

2. Persons (e.g. children) weighing more than 20 kg.

It is not applicable to the detection of persons weighing less than 20 kg.

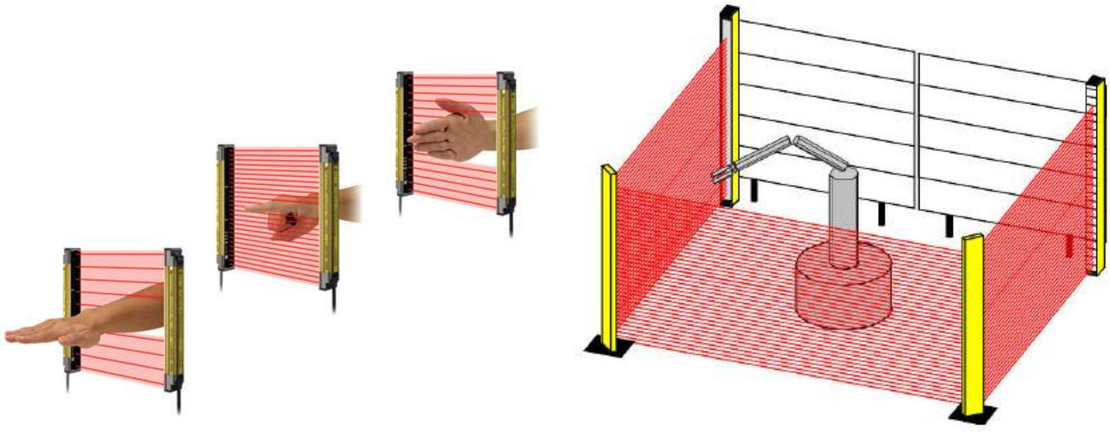
It does not specify the following because they are application specific:

1. Dimensions or configuration of the effective sensing area of pressure-sensitive mat(s) or pressure-sensitive floor(s) in relation to any particular application

2. When pressure-sensitive mats or floors are appropriate in a particular situation

3. Performance levels (PLs) for safety-related parts of control systems (SRP/CSs) other than providing a minimum level

Light Curtains If an obstruction is detected within the path of the light beam, an output is triggered. This method provides instant access to the workspace, and multiple instances can provide different safety zones. However they cannot shield against projectile hazards.



(a) (b)

Figure 13: Light curtain for robot workspacet

Source: `www.globalspec.com`

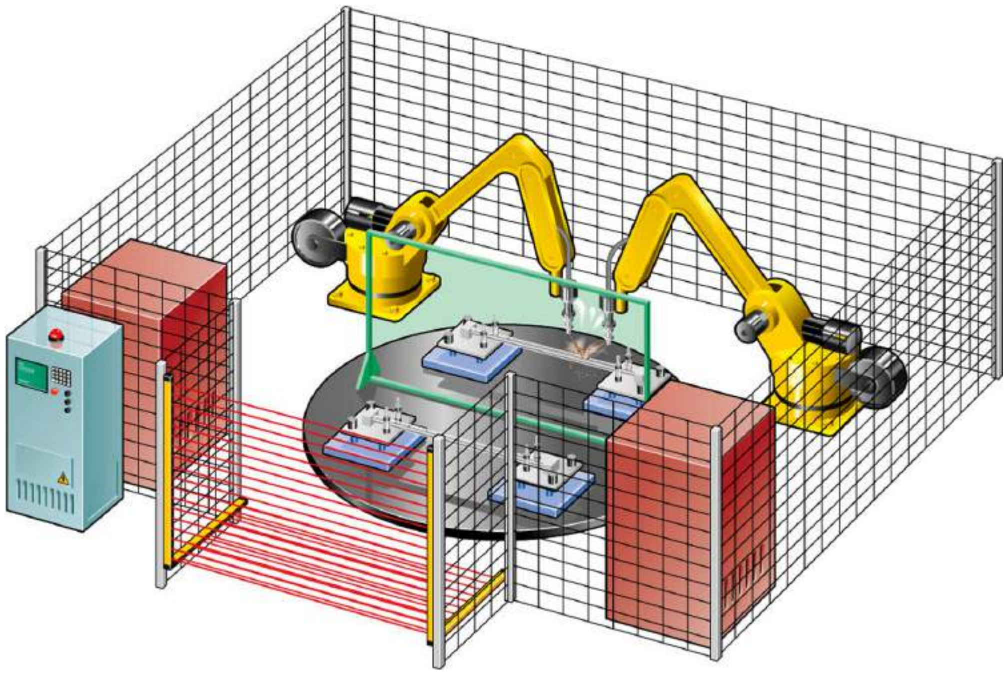


Figure 14: Light curtain, pressure mat, perimeter fence for an industrial robot

Source: `www.fabricatingandmetalworking.com`

Laser scanning devices These devices use a single laser beam to map an area and detect any changes which would signify a potential hazard, and trigger an output. These devices normally operate below the working level of the robot.

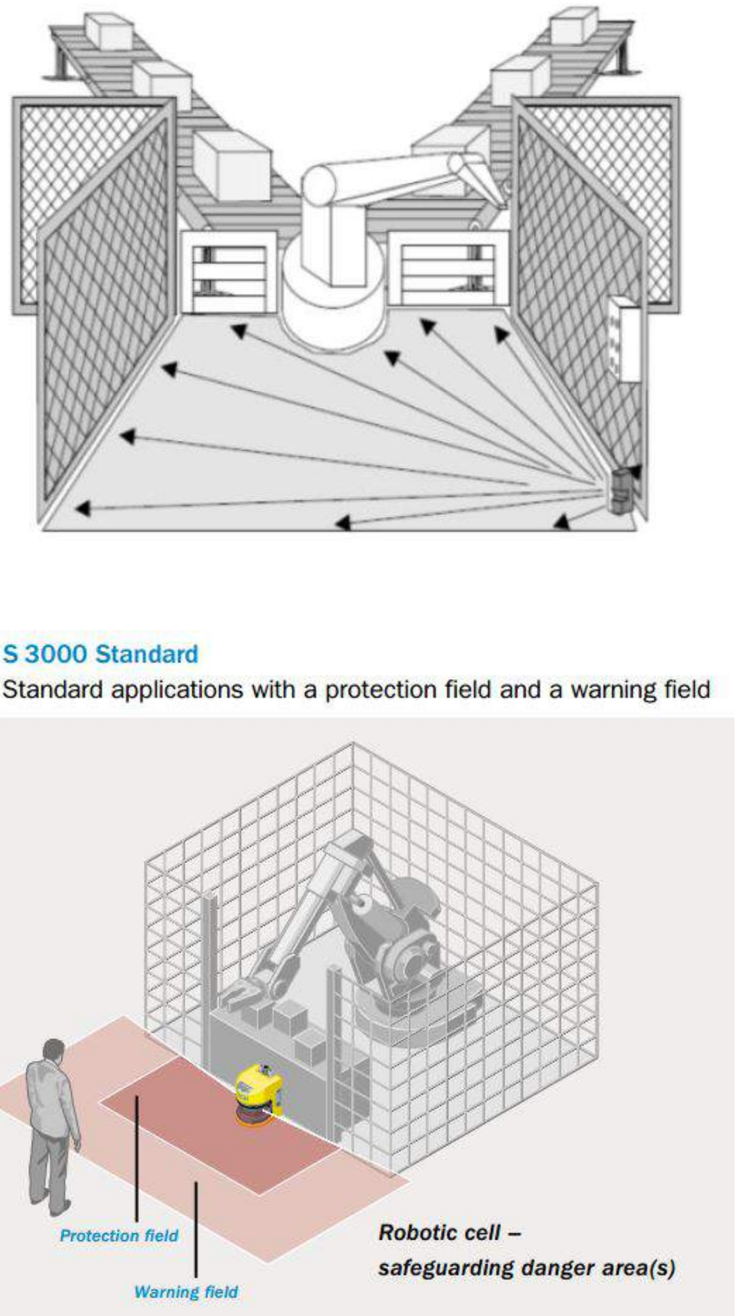


Figure 15: Access area safeguarding with laser safety scanner

Source: SICK Sensor Intelligence `www.sick.com`

3.6 Robotic Cable Management

Robotic Cable Management is crucial to ensuring these cables work at their potential for as long as possible. When improperly housed, cables will wear prematurely or fail in other ways, causing downtime. Unhoused, cables can sag and fall into the work area, or become tangled within the moving parts of the machinery.

Often overlooked, housing the cable bundle properly around a robot is critical in maintaining proper performance and avoiding machinery downtime.

Some common types of solution used in industry are

1. Flexible tubing
2. Drag chain
3. Enclosed dress packs
4. Robotic cable carrier (Eg: igus triflex R)

Figure 16: Cabel channelization on the Robot

Source: Kuka robotics

Figure 17: Drag chain on the machine

Source: HOMAG group

3.7 Electrical Safety system

MCBs A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by overcurrent or overload or short circuit. Its basic function is to interrupt current flow after protective relays detect a fault. Unlike a fuse, which operates once and then must be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation.

Once a fault is detected, the circuit breaker contacts must open to interrupt the circuit. Some mechanically stored energy (using something such as springs or compressed air) contained within the breaker is used to separate the contacts, although some of the energy required may be obtained from the fault current itself. Small circuit breakers may be manually operated; larger units have solenoids to trip the mechanism, and electric motors to restore energy to the springs.

Figure 18: Miniature Circuit Breaker

Source: MCB, Wikipedia

Earthing Systems In electricity supply systems, an earthing system or grounding system is circuitry which connects parts of the electric circuit with the ground, thus defining the electric potential of the conductors relative to the Earth's conductive surface. The choice of earthing system can affect the safety and electromagnetic compatibility of the power supply. In particular, it affects the magnitude and distribution of short circuit currents through the system, and the effects it creates on equipment and people in the proximity of the circuit.

If a fault within an electrical device connects a live supply conductor to an exposed conductive surface, anyone touching it while electrically connected to the earth will complete a circuit back to the earthed supply conductor and receive an electric shock.

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